Recapping…

Disk galaxies show trends

Low luminosity / low surface brightness galaxies: lower in metallicity, bluer, more gas-rich, and their gas is mostly atomic.

High luminosity / high surface brightness galaxies: higher in metallicity, redder, lower gas fractions, more of their gas is in molecular phase.

Disk galaxies show gradients

Outer regions are lower in metallicity, bluer, more gas-rich, and atomic gas dominated.

Inner parts are higher in metallicty, redder, less gas-rich, and more molecular gas.

Note: many exceptions exist, enough so that there are whole classes of galaxies that defy these relationships. But as a general thumbnail sketch of galaxies, this is reasonable.

Spiral Galaxies: Star Formation rates

Global star formation rates (SFR): ~ 0.01 – 100 $M_\odot$/yr
Milky Way SFR ~ 1 $M_\odot$/yr

Gas depletion times: $\tau = \left(\frac{M_{gas}}{SFR}\right) \sim 10^8 - 10^{10}$ yr

SFR often parameterized via Schmidt (1959) law

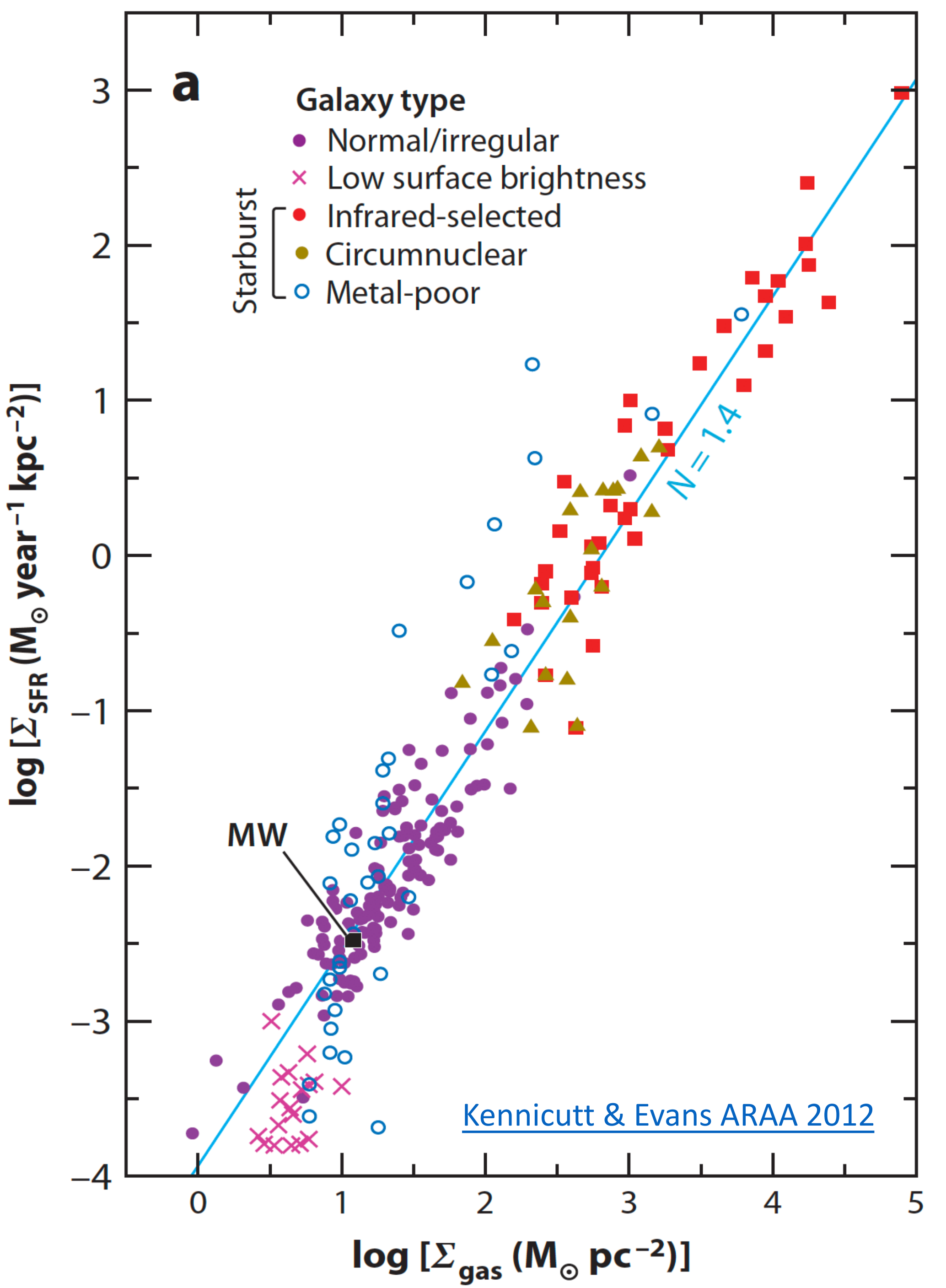
$$\Sigma_{SFR} \sim \Sigma_{gas}^N$$

Σ_{SFR} is SFR per area
$M_\odot$/yr/kpc^2

N>1 means there's more to SFR than just having fuel.

- Collisions of gas clouds? $N{\sim}2$
- Gravitational collapse? $N{\sim}1.5$

$$t_{dyn} \sim \frac{1}{\sqrt{\rho_{gas}}} \rightarrow SFR \sim (\rho_{gas}/t_{dyn}) \rightarrow SFR \sim \rho_{gas}^{1.5}$$



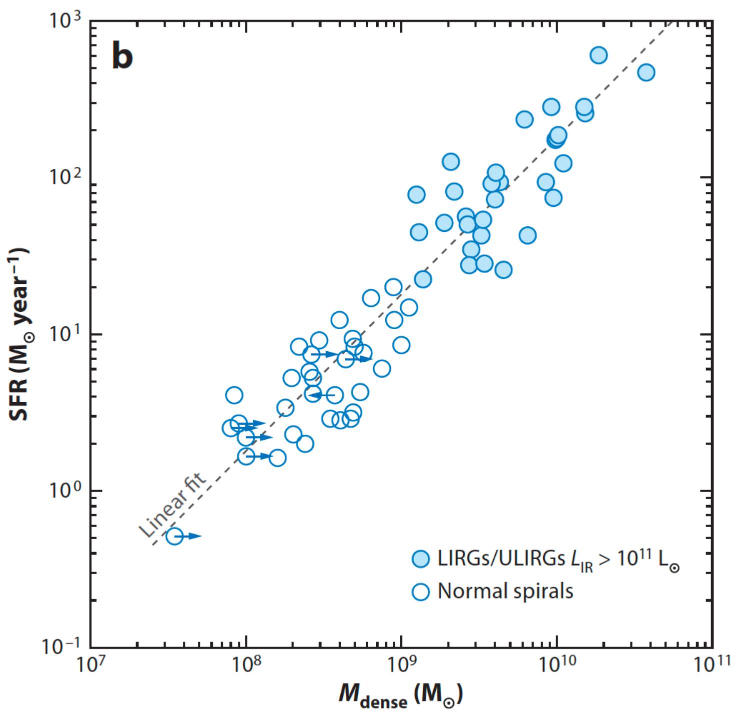
Spiral Galaxies: Star Formation efficiency

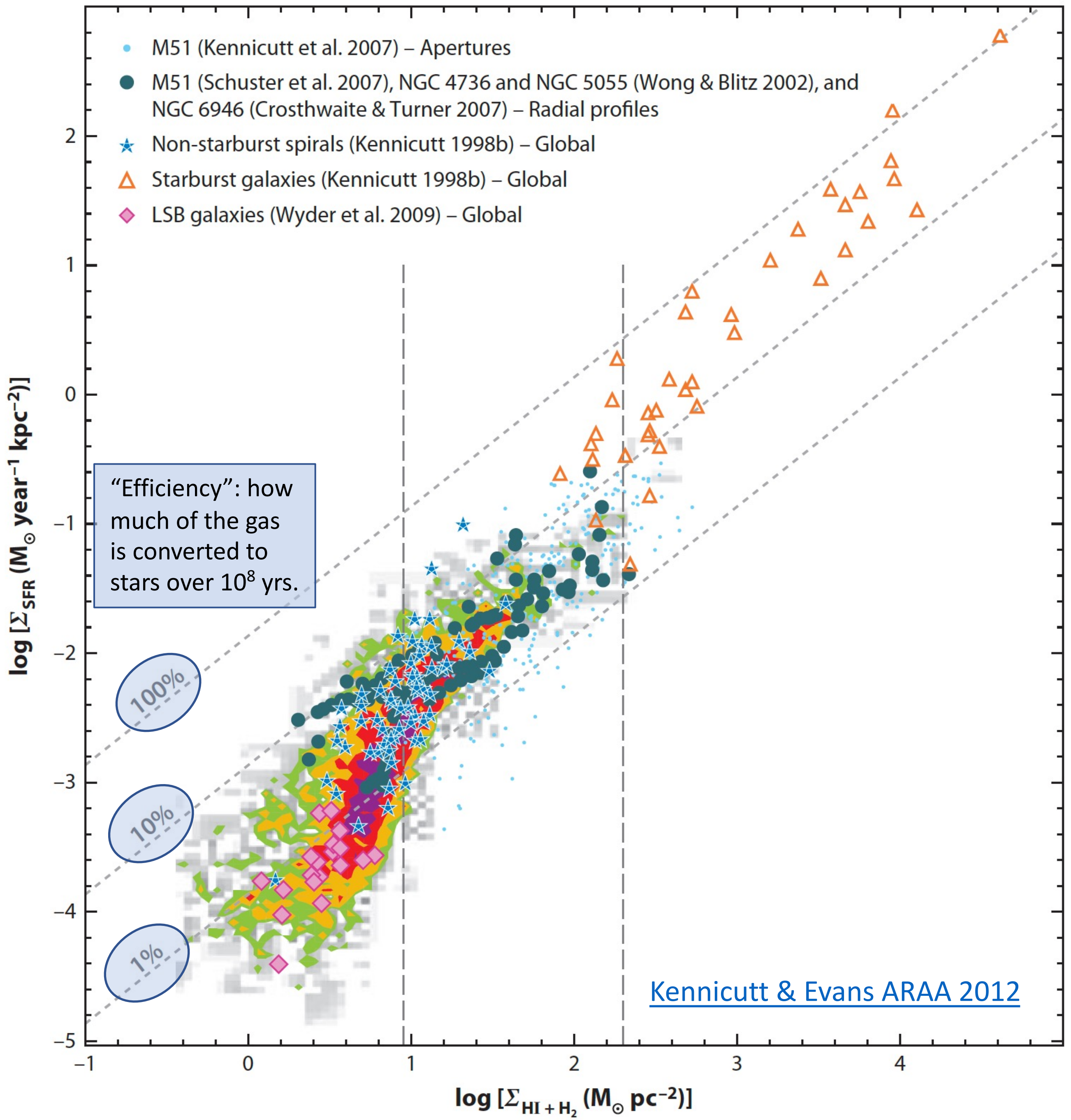
Another way to think of it is a changing efficiency as a function of density:

"efficiency": fraction of gas converted to stars over a characteristic timescale.

Higher gas density ⇒ higher star formation efficiency

SFR correlates directly (N=1) with ***dense molecular gas!***





Spiral Galaxies: Star Formation efficiency

Density drives star formation, but via the formation of molecular gas.

Low density environments (galaxy outskirts, low surface brightness galaxies) are rich in HI, but cannot easily form molecular gas.

Star formation in these environments is weak and sporadic.

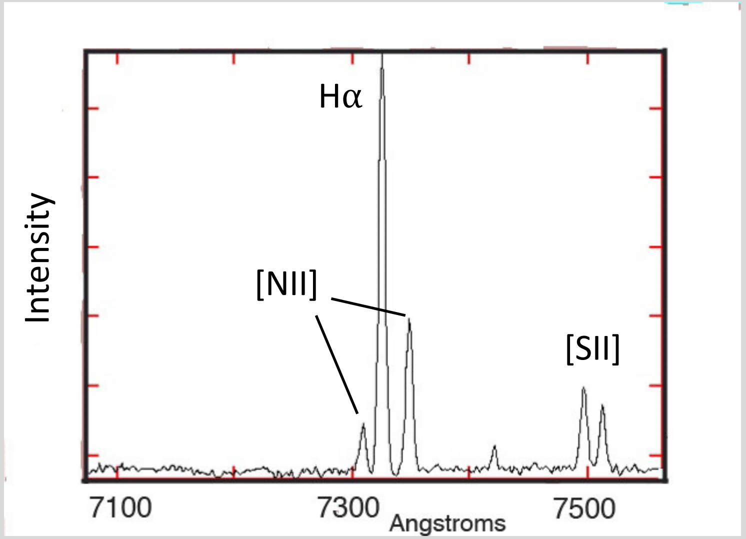
Evolution is mild: low SFRs, low surface brightness, low metallicity.

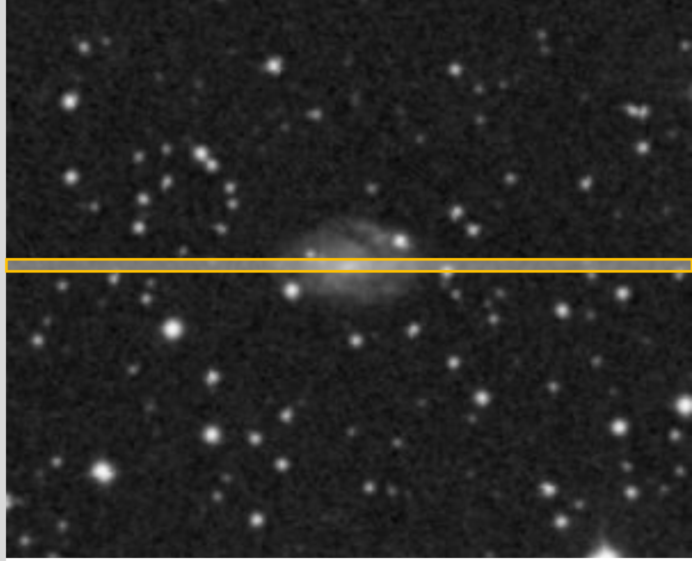
Characteristic colors are bluer: less integrated SFR to build up older populations.

HSB: M101

LSB: Malin 1

Measuring Rotation: Longslit spectroscopy



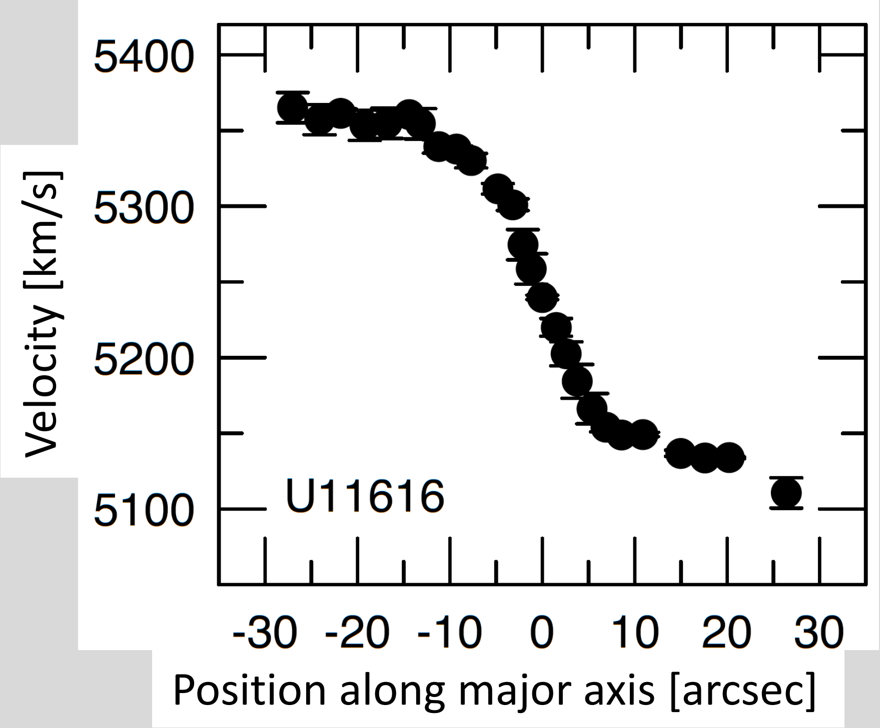


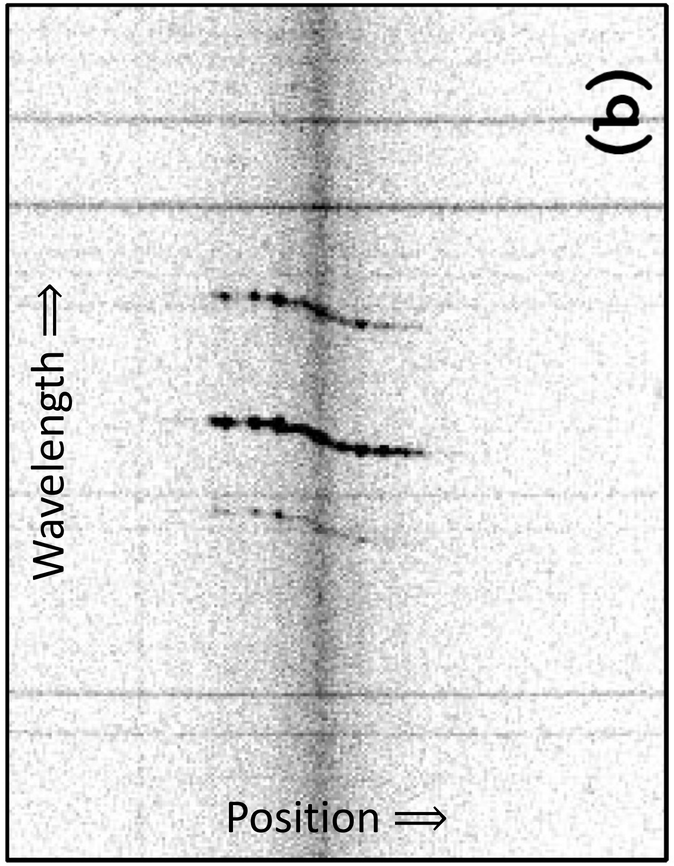
Place a spectrograph slit across the major axis of a galaxy, measure the wavelength of emission lines, get velocities from Doppler shift.

Need to correct rotation velocity for inclination of galaxy.

$$V_{c,obs} = V_{c,true} \sin i$$

face-on: $i = 0°$
edge-on: $i = 90°$





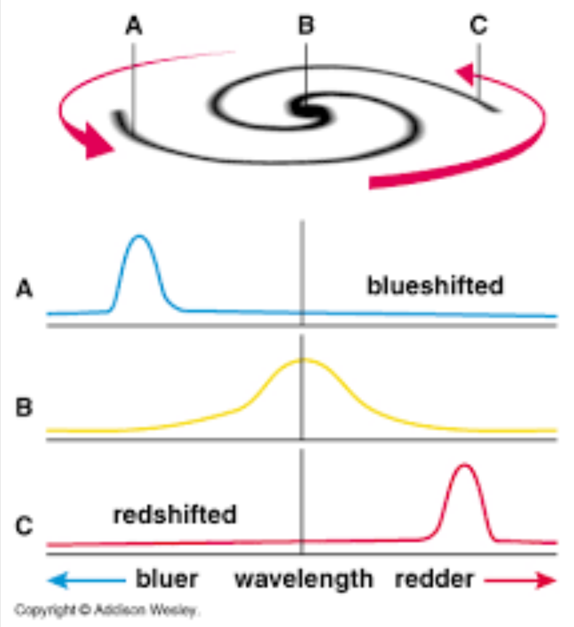
McGaugh+ 01

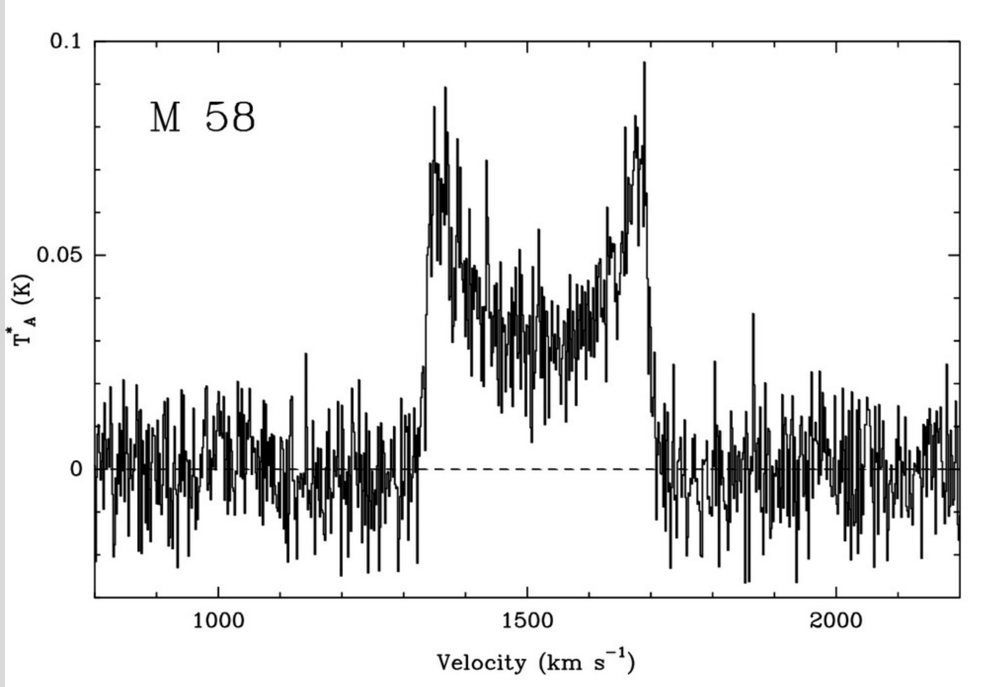
Measuring Rotation: 21-cm line / Single dish radio telescopes

Look at HI 21-cm emission line.

Drawback: Individual radio telescopes have relatively poor spatial resolution. So we can't map the rotation curve in detail, but we can still estimate the rotation speed of a galaxy.

If we add up all the 21-cm emission from a rotating galaxy, what would we expect the emission line profile to look like?





"Double horn profile"

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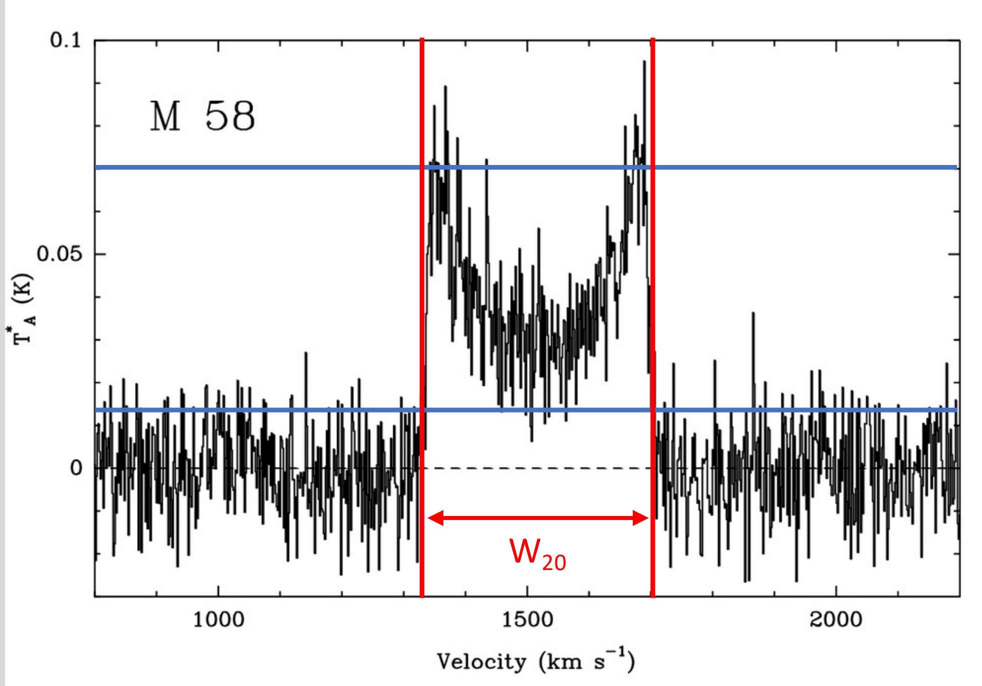
Measuring rotation from the velocity width

Define W_{20} as the width (in km/s) of the 21-cm emission where it drops to 20% of its peak value.

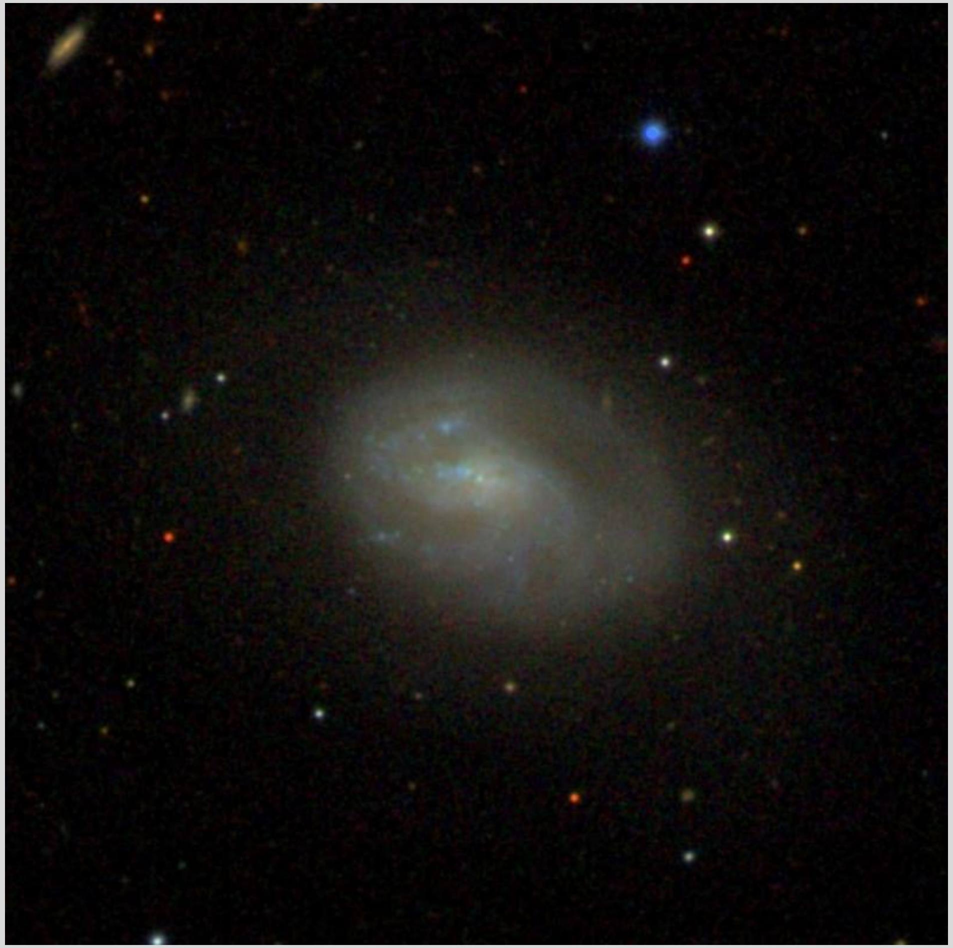
Then $W_{20} \approx 2V_c \sin i$

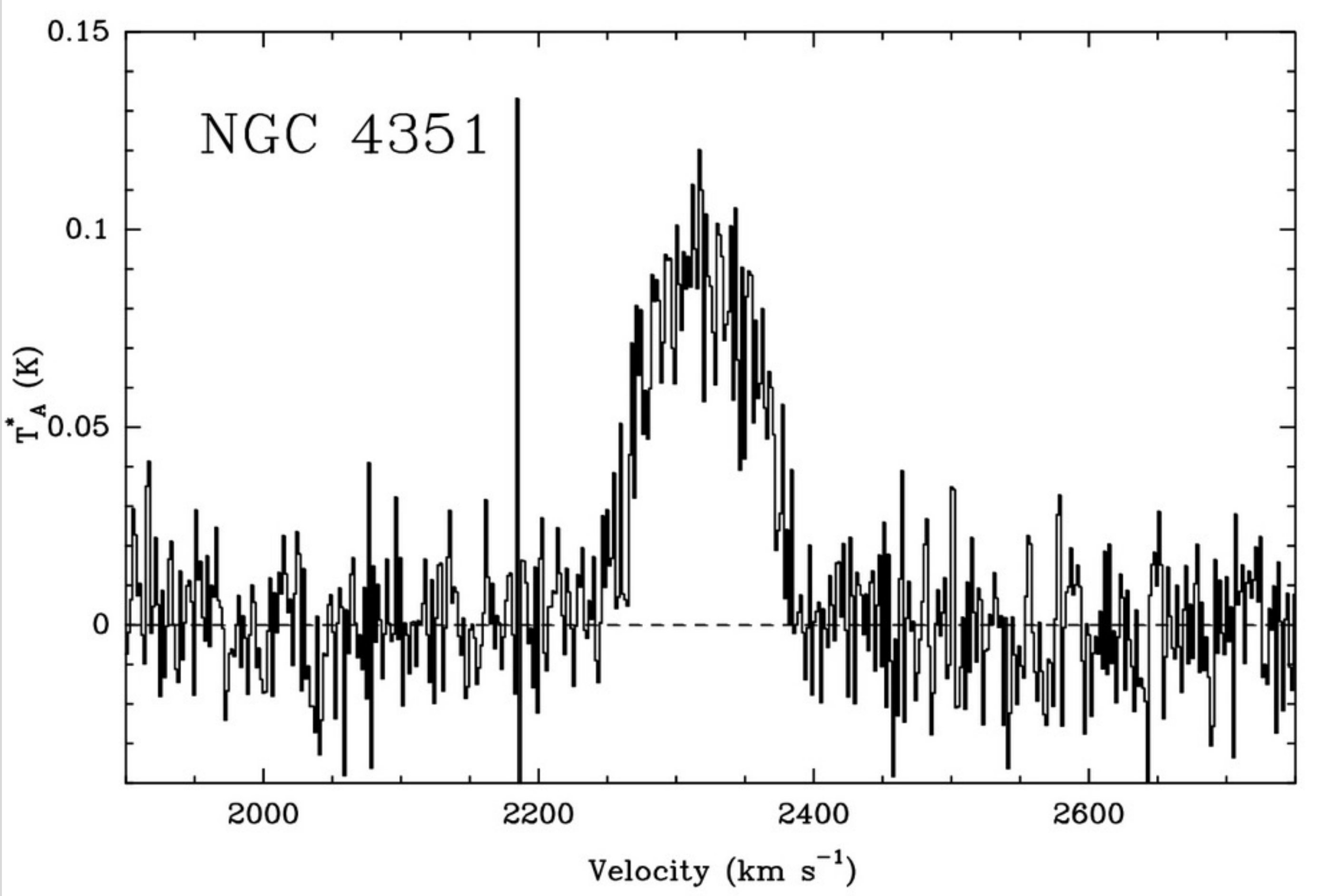


Measuring Rotation: 21-cm line / Single dish radio telescopes

Not every galaxy is so well behaved, though. The gas may not be as radially extended, so no “double horn” profile.

NGC 4351



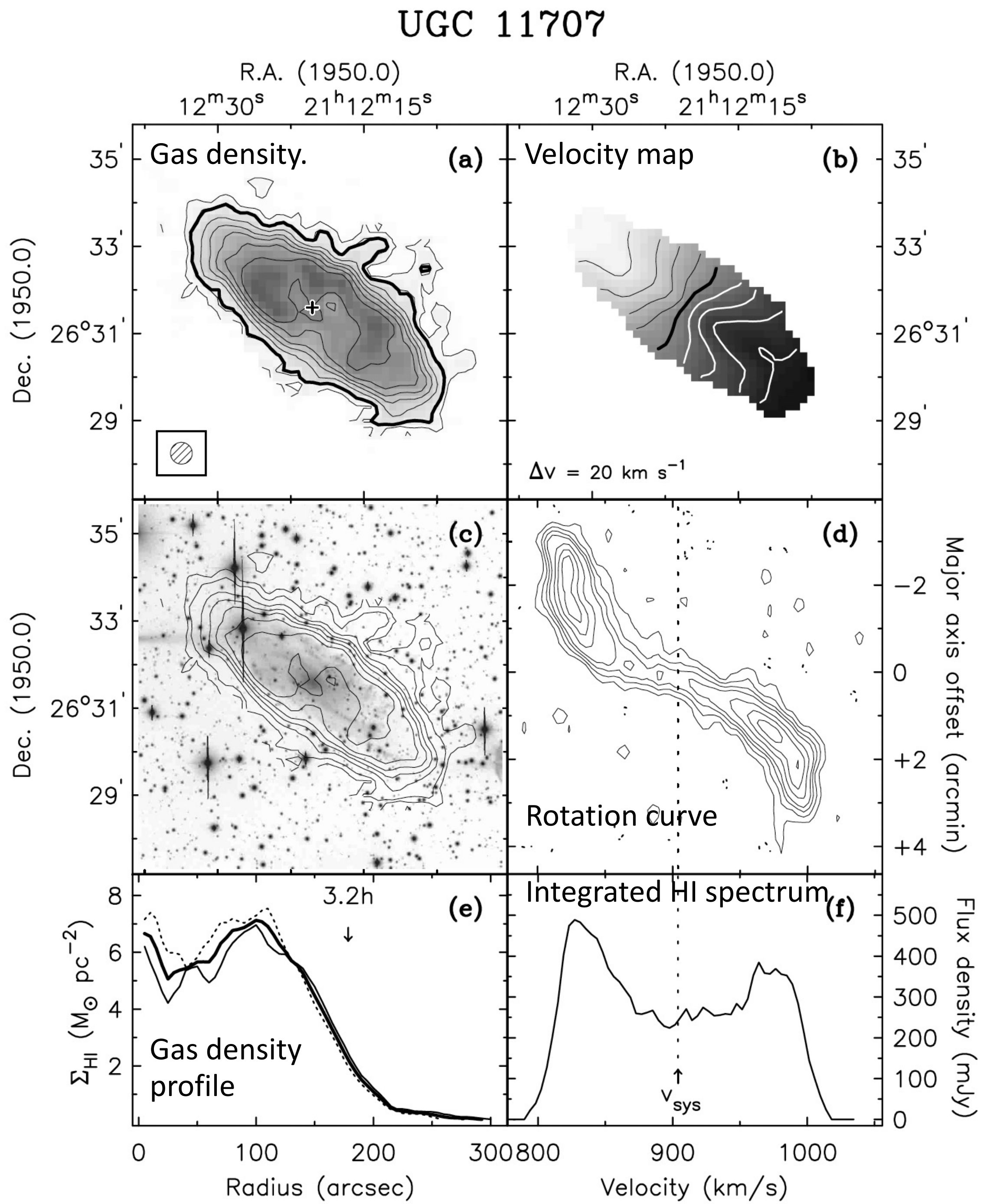


Measuring Rotation: 21-cm interferometry

Radio telescope arrays use interferometry to get good spatial resolution. Image the galaxy in 21cm, scanning the receiver in wavelength.

Each spot in the galaxy yields a 21-cm line spectrum, which tells you HI intensity, velocity, velocity width (dispersion). Construct a 2D map of the projected velocity field.

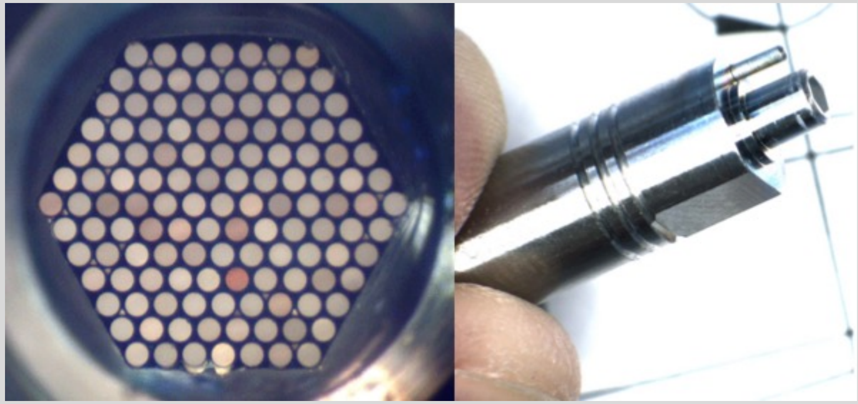
Fit to a 2D rotating disk model to derive rotation curve.

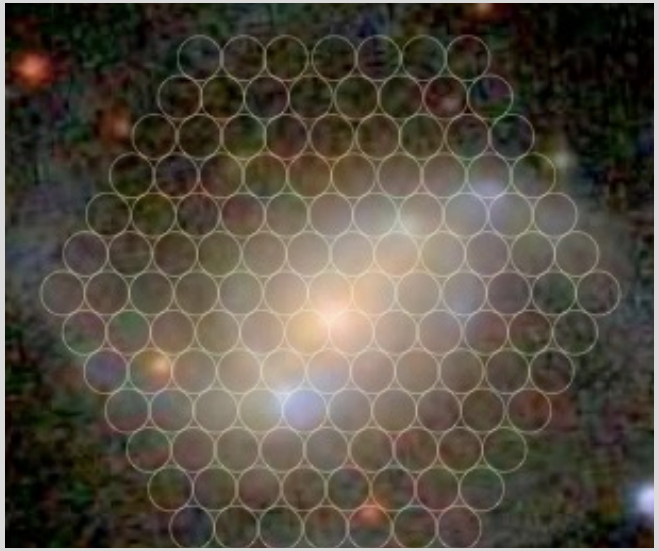


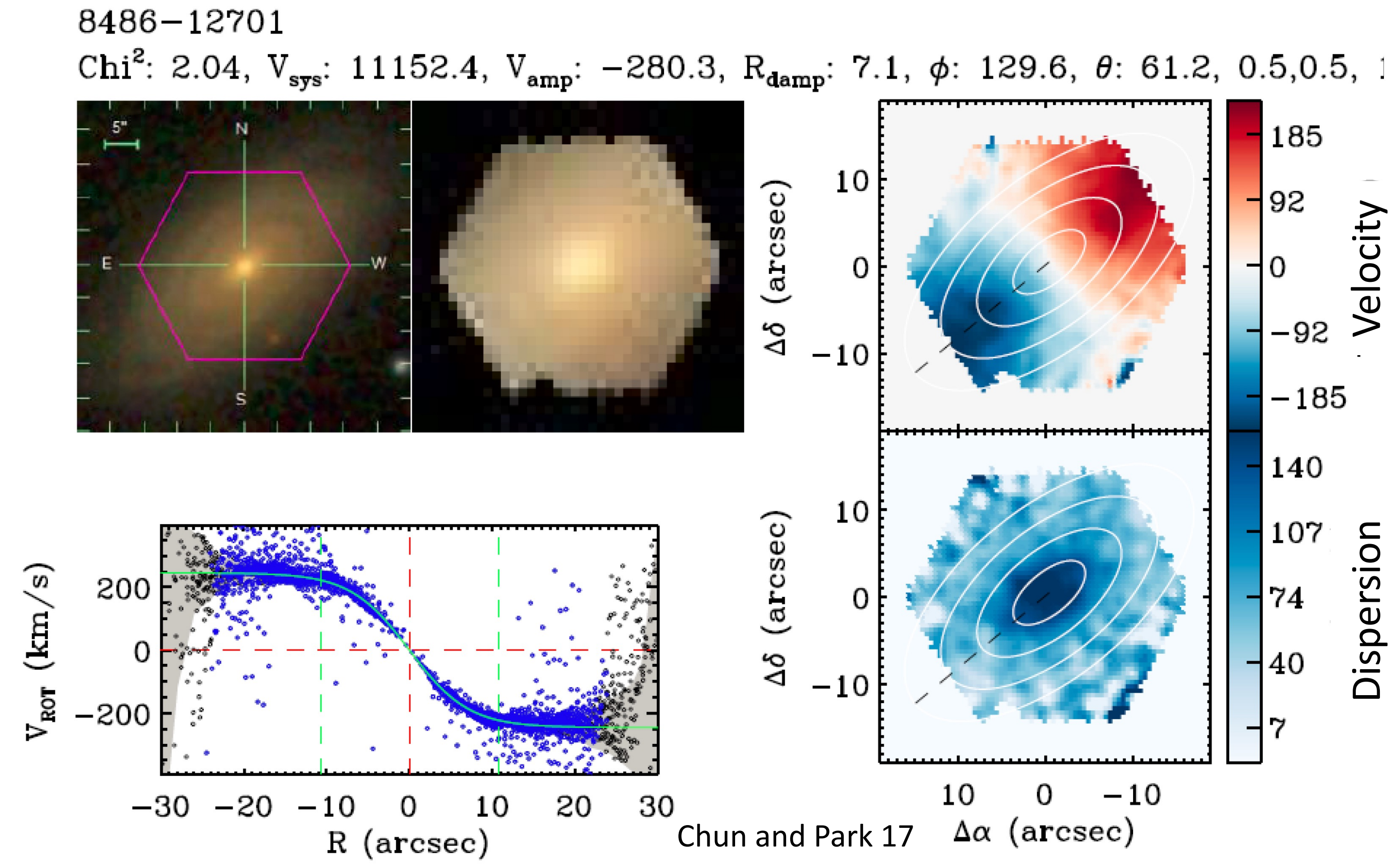
Measuring Rotation: Integral Field Spectroscopy

Instead of a spectrograph slit, use densely packed bundle of optical fibers to put light into the spectrograph.

Provides 2D mapping, like interferometry, but gives full optical spectrum at every position : emission lines (gas kinematics, metallicity), absorption lines (stellar kinematics, metallicity), spectral shape (stellar populations), etc!







Chun and Park 17

Rotation Curves of Spiral Galaxies

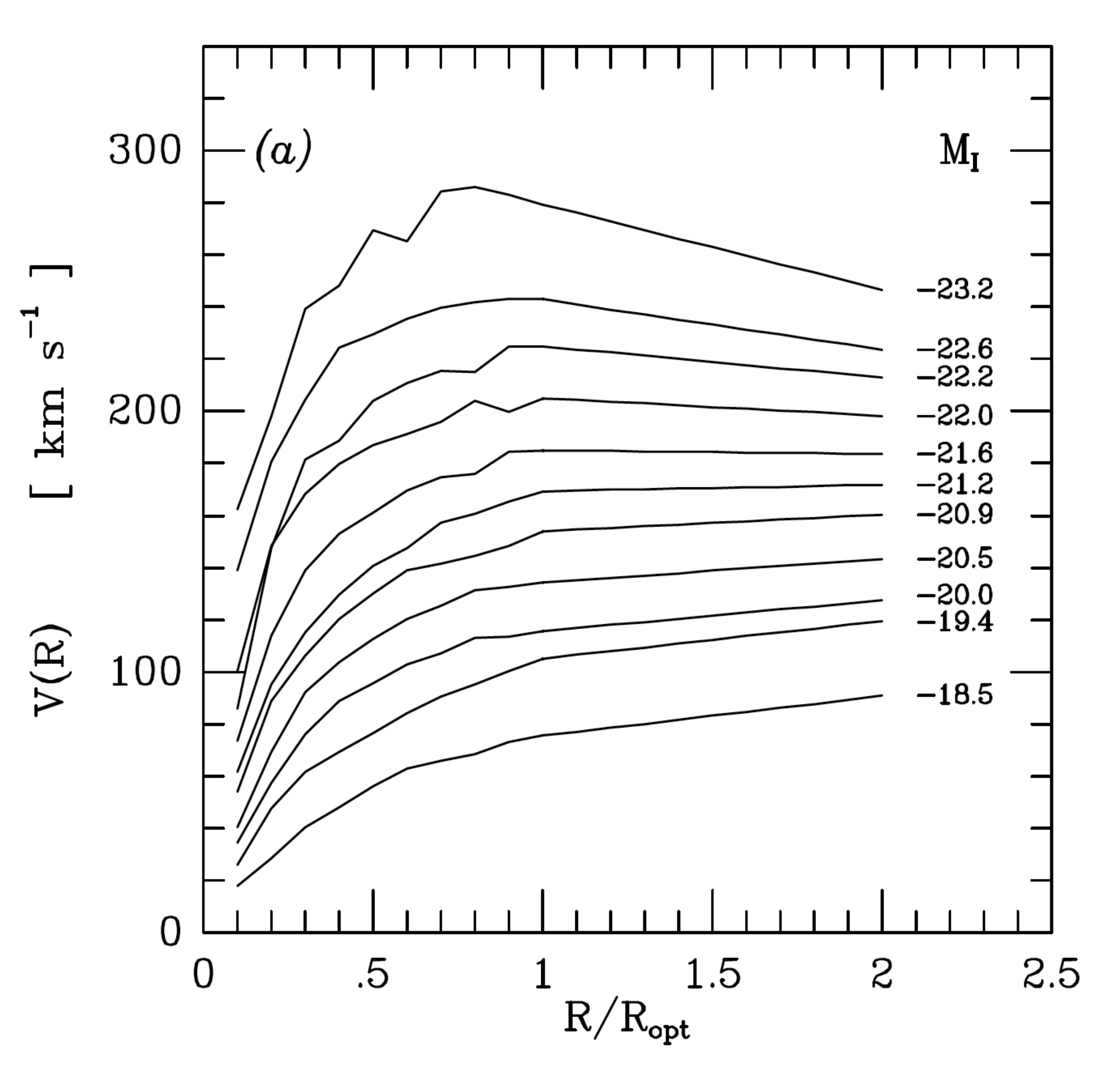
Systematic Trends

More luminous galaxies rotate faster: **Tully-Fisher Relation**

Rotation curves are generally flat in their outskirts. Falling rotation curves almost always due to

- Bright inner disk/bulge (high stellar density)
- Disturbances in outer disk (non-rotational motion)

Rotation curves always rotate too fast for their total stellar mass ⇒ dark matter or modified gravity.



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